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ABSTRACT

The relative effectiveness of digital versus photographic images was examined with 96 college students as subjects. A 2x2 balanced factorial design was employed to test eight hypotheses. The four groups were (1) digitized black and white; (2) digitized pseudocolor; (3) photographic black and white; and (4) photographic realistic color. Findings suggest that the use of the digitized black and white images in computerized instruction and information transmission of pictorial information provides the same pictorial information as use of the photographic black and white pictures. Adding pseudocolor to the digitized black and white photographs did not increase the distinctiveness and recognition of these pictures in the task. While there was no significant difference between the photographic black and white and photographic realistic color, photographic realistic color was preferable to digitized pseudocolor in learning from realistic scenes. Findings partially support the contention of realism theories, but the cue-summation theory was not supported by any of the findings. (LMM)

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A SIGNAL DETECTION ANALYSIS OF DIGITIZED AND PHOTOGRAPHIC IMAGE MODES AND COLOR REALISM IN A PICTORIAL RECOGNITION MEMORY TASK

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A SIGNAL DETECTION ANALYSIS OF DIGITIZED AND PHOTOGRAPHIC IMAGE MODES AND COLOR REALISM IN A PICTORIAL RECOGNITION MEMORY TASK

ABSTRACT

In this study, signal detection theory analysis is used to investigate the relative effectiveness of digital versus photographic images in a pictorial recognition memory task.

Digital images are the result of advances in computer graphics and digital image processing and may facilitate the recognition of images by human subjects. The ability to manipulate the pseudocolor in the digital image can result in forms and arrays which can be more easily distinguished from one another, thereby increasing the probability of a particular image being recognized.

Subjects consisted of 96 college students. A 2x2 balanced factorial design was employed to test eight hypotheses. The four groups are: (1) Digitized black and white (DBW), (2) Digitized Pseudocolor (DPC), (3) Photographic black and white (PBW), and (4) Photographic Realistic Color (PRC). The original pictorial materials in the study were selected from the pictorial materials developed by Berry (1977). Those pictorial materials (140 35mm in B&W and in Color) were manipulated photographically and by the image processing system (PRL) to produce the four treatments.

A two-way anova and one-way anova followed by Tukey-B multiple comparison test were conducted on three of the signal detection theory parameters, d', A' and A_G to test the study hypotheses and the differences among the experimental groups at significance level $\alpha = .05$.

Introduction

Computer graphics and digital image processing are providing a relatively new and rapidly growing type of pictures known as the digital images and will be termed here as digital imagery mode as opposed to the photographic imagery mode. Digital images are numerical representations of different types of pictorial methods, including B&W photographic pictures, by using different types of sampling and quantization techniques of gray levels. Computers can manipulate the psycho-physical characteristics of pictures by processing their digital forms. As a result, pictures gain better contrast and better quality. Pseudo-color can be added to pictures according to the gray level of their elements which are called pixels. The use of color in digital pictures with suitable choices of shade, degree of brightness and level of saturation will increase the amount of information that can be conveyed . This is based on the psychological fact that the human visual and perceptual system can easily discern thousands of shades and intensities of color but only 20 to 30 shades of gray (Gonzalez, 1977). Psycologically, in view of the cue-summation theory (Severin, 1967) in learning, color adds more cues that aid the learner in processing and recognition of pictorial information. There are some speculations and theoretical views that claim that digital images with enhancement taking place become more suitable for human processing and recognition (Moik, 1980). Digital images are characterized by being discrete in their gray level. The display of digital images at some magnification power makes the picture elements(pixels) start to be visible. The quality of digital images depends on the display subsystem of the digital image processing system and the method used in making hard copies such as slides or prints. Slide-making and print-making equipments are started to be parts in the image processing systems,

but they are not available in most research laboratories of image processing. Photographing the screen of the display subsystem of the image processing sytems is considered a true way of obtaining the picture resolution and grey level (Sze, 1982). This method is largely used to make hard-copies of the digital images. On the other hand, the conventional photographic mode provides a more realistic representation of the real situations such as realistic color. This color realism, in view of realism theories (Dwyer, 1967), is claimed to be more effective in pictorial processing and recognition. The relative effectiveness of both the imagery modes, digital and photographic, in designing effective visual communication, iconic delivery and representation of information, and visual learning can not be predicted without systematic research. Realism theories as well as the cue-summation theory can not easily be applied to predict the effectiveness of the two imagery modes simply because studies have revealed some inconsistencies (Berry, 1982). Extensive studies are needed to investigate the effectiveness of the two imagery modes, digital and photographic modes and the type of color in pictorial recognition memory task.

Rational of The Study

Digital images are considered a potential source of visuals for visual learning and computer assisted instruction (CAI). Research is needed to examine the effectiveness of the digital image attributes in the design of effective visual learning and instruction. Pseudo-color and enhancement are two attributes of the digital images that need to be studied to discover their effect and function in visual learning and recognition.

The function of pseudo-color in picture processing is to increase the effective

viewing of the gray scale of the original image (Andrews, 1974). The study of the effectiveness of image enhancement needs to be carried on in an objective way. Andrews (1979) has pointed out the difficulty found in the evaluation of optimum color mapping in the pseudocolor because of the subjectivity of both enhancement and color viewing. Hall (1979) has pointed out that the quality improvement in image enhancement is not objectively defined. One way to find solutions to such problems is to conduct controlled experiments to study the effectiveness of different digital image enhancements in visual learning tasks such as pictorial recognition memory. Lipkin and Rosenfeld (1970) in their book, Image Processing and Psychopictorics, have stated that:

> ... The art of picture processing by computer has reached the point where on-line, real-time manipulation of images is now possible, this making it feasible to conduct controlled experiments of the perception of natural pictures ... (p. vii)

This experimental approach to study the effectiveness of image processing and enhancement on the human viewer's perception, understanding, and recognition defines the human link in the image processing system (Hall, 1979). Such a link between the individual and the digitized image in comparison with the photographic image and color realism should be subjected to extensive studies.

The presence of color in visual learning and memory is one of the major issues in the design of media for learning and instruction. Studies which have been carried out on color and pictorial memory have resulted in a set of contradictory findings. Myatt (1974) carried out a study on pictorial attributes and pictorial recognition memory . In that study, Myatt (1974) found that color didn't appear to be a significant factor in pictorial recognition memory in any of the three experimental

groups. Myatt found also that color didn't appear to be a significant factor in recognition memory at any level of the three levels of pictorial information: low, medium, and high. Studies (Berry, 1974; Dwyer, 1971) concluded that color is a significant dimension in the design of instruction. The same conclusion was supported by later studies. Color was found to increase or to improve pictorial recognition memory more than black and white presentations (Berry, 1977; Wieckowski, 1979; Chute, 1980; Lertchalolarn, 1981). In a review of color and the learner, research shows that learners do prefer color in media presentations (Descy, 1981). Studies that investigated the color realism showed that there was no significant difference between the realistic and the non-realistic color in pictorial recognition memory (Berry, 1977; Lertchalolarn, 1981).

The Signal Detection Theory (SDT) and Pictorial Recognition Memory

Research methods in recognition memory are more standardized than methods of data analysis used by researchers. The recent applications of the SDT model in human perception, detection, attention, vigilance, inspection, and recognition studies have made researchers like Murdock (1982), Berry (1982), and Swets and Pickett (1982) argue against the use of other approaches applied by researchers in measuring the recognition memory as being inadequate. In typical old-new recognition memory experiments and elsewhere, researchers have used different measures of accuracy of the discrimination between old and new items such as: the conditional probability of old items, the conditional probability of the old items paired with the conditional probability of correct rejection, the overall probability of correct responses, the a posteriori of old items, and the ratio of the a posteriori probability of old items to the

a posteriori . Swets and Pickett (1982) have warned against the use of those because they do not take into account the decision criterion. Murdock (1982) says that decision factors certainly affect performance on many tests of recognition memory and this may lead to erroneous conclusions on the part of the experimenter. Murdock (1982) and Berry (1982) agree that using signal-detection analysis in recognition memory provides the statistic d' (d-prime) that characterizes the overall accuracy that combines both old items and new items. The d' index used in Signal Detection Theory (SDT) has been described in various publications and research articles (Green, 1966; Swets, 1964; Bourbon, 1978; Swets, 1982; Berry, 1982). The accuracy and the application of d' in pictorial recognition memory have been demonstrated by Berry (1982). The SDT index d' has been supported, preferred, and justified as an adequate measure of recognition memory for its depth and accuracy (Murdock, 1982; Berry, 1982; Banks, 1970; Lockhart & Murdock, 1970; Murdock, 1964).

The SDT index d' assumes that the observer establishes normal equi-variance distributions of the memory trace strength of the old items (O) (Signal + Noise) and the new items (N) (Noise) (Murdock, 1974). Moreover, d' is indetermined when either the hit rate is one or the false alarm rate is zero (Berch, 1975). The violations of that distributional assumption result in erroneous conclusions concerning d', meaninglessness of d', and a significant correlation between d' and the criterion β (Beta). Long and Wagg (1981) have found from empirical data in situations like vigilance, visual search, and auditory recognition that the violation of the distributional assumption has resulted in an inadequacy of d'. Researchers like Norman (1964), Pollack and Norman (1964), Hodos (1970), Richardson (1972), Berch (1975), Craig (1979), and Long and Wagg (1981) have started to consider non-

parametric measures for detection and recognition. The area under the Receiver Operating Characteristic graph (ROC-Curve) provides two other parameters : A' and A_G. A' and A_G are distribution-free measures of response sensitivity and have been used in detection and recognition. The index A' has been described and developed by Norman (1964) and Pollack and Norman (1964). The computational formula of A' was developed by Grier (1971) and was used in research by Craig (1979) in vigilance and by Berch (1975) in recognition memory. The measure A_G is another measure of the area under the SDT ROC curve. It has been described by Green and Swets (1966) and used by Craig (1979). Since, in old-new recognition memory experiments, the distributional assumption of d' can not be verified, the author will use two distribution-free measures of recognition memory (A' and A_G) besides the SDT parameter of detectability (d').

The Problem of The Study

The present study was designed to investigate the interactive effects of digital image and photographic image modes and color realism on a pictorial recognition memory task. The Signal Detection Theory (SDT) was used to model the recognition memory task. Three indexes from the SDT were used to analyze the pictorial recognition data: the d-prime (d'), A-prime (A'), and A_G. The problem was defined in the following research questions:

1. Is there a significant interaction between color modes (B/W and color presentation) and the imagery modes (digital and photographic images) in a pictorial recognition memory task?

2. Is there a significant main effect of color presentation (B/W and color modes) in a pictorial recognition memory task?

3. Is there a significant main effect of imagery modes (digital and photographic image modes) in a pictorial recognition memory task?

4. Is there a significant difference between the means of the four treatments, digitized B&W, photographic B&W, digitized pseudocolor , and photographic realistic color, in a pictorial recognition memory task?

5. Is there a significant difference between the realistic color in photographic images and the pseudocolor in digitized images in a pictorial recognition memory task?

6. Is there a significant difference between digitized B&W images and photographic B&W images in a pictorial recognition memory task?

7. Is there a significant difference between digitized pseudocolor images and digitized B&W images in a pictorial recognition memory task?

8. Is there a significant difference between photographic realistic color and photographic B&W images in a pictorial recognition memory task?

The significance of The Study

There are three major contributions of this study in three aspects: practical, theoretical and methodological.

1. In the practical aspect, this study will provide contributions to:

   A. The discovery of the effective use of digital images in designing Computer Assisted Instruction (CAI) and visual learning.

   B. The discovery of the effectiveness of both image enhancement and pseudo-color addition in pictorial recognition memory.

   C. The discovery of the relative effectiveness of the realistic color and the pseudo-color in pictorial recognition memory.

   D. The discovery of the effects of the manipulation of some physical characteristic memory.

2. In the theoretical aspect, this study is an investigation of the contention of realism theories versus cue-summation theory in the prediction and interpretation of visual learning as applied to different imagery modes.

3. In the methodological aspect, this study is using the Signal Detection Theory in the analysis of the recognition data. Two new parameters from the ROC curve in SDT (A' and A_G) were used in the analysis besides the use of the d' (the index of SDT detectability).

Methodologies and Procedures

The Subjects

The subject of this study were university students: graduates and undergraduates . Students signed-on for participation. Sign-on scheets were made available to students in most of the University of Pittsburgh libararies, classes, reserve book rooms and bulletin boards. From a total of 120 subjects participating in the study, 96 completed the experiment according to the instructions.

Subjects were randomly assigned to the four experimental groups of the 2X2 factorial design. Data were collected on the subject's age, major of study, study level and sex. The Subjects' ages were in the range 17 to 57, the average was 27.7 years, the median was 24 years and one subject did not report his/her age. Subjects were majoring in 48 different areas of study. Fourty five of the subjects were males, 50 were females and six students didn't report their sex. Fifty four of the subjects were undergraduates, 32 were graduates and 10 did not report their study level. These descriptive data show that subjects were varied in their age, major of study, level of study and sex. Subjects were evenly distributed between the four experimental groups: Group 1.1, Group 1.2, Group 2.2 and Group 2.2.

The Study Variables and Design

In this study, there were two independent discrete variables (factors) and one Pictorial recognition memory was the dependent variable which has been measured by the use of the signal detection analysis. The following are the variable classification and their codes as used in data processing and analyses:

1. The color modes of the images: B&W mode and the color presentation mode. Color modes (Color) was used as one of the two factors in this study.

2. The imagery modes of the pictures: digital imagery mode and photographic !magery modes (Immode) was the second factor of the study design.

3. The recognition memory, the dependent variable, as measured by the signal detection parameters in two types of analyses: Yes-No signal detection parameters. The Yes-No signal detection parameters used to measure recognition memory were: d', A' and A_G(area under ROC measure described by Green and Swets (1966)).

To investigate the research questions of this study, a 2X2 balanced factorial experimental design was used. This design is illustrated in Figure 1.

Figure 1 shows that Group 1.1 performed the pictorial recognition task using the digitized B&W pictures(DBW), Group 1.2 performed the pictorial recognition task using the digitized pseudocolor pictures(DPC), Group 2.1 performed the pictorial recognition task using the photographic B&W pictures(PBW) and Group 2.2 performed the pictorial recognition task using the photographic realistic color pictures(PRC).

		COLOR MODES: B&W	COLOR MODES: Colored
I M A G E	Digital Image Mode	24 Group 1.1 Digitized B&W DBW	24 Group 1.2 Digitized Pseudocolor DPC
M O D E S	Photo-graphic Image Mode	24 Group 2.1 Photographic B&W PBW	24 Group 2.2 Realistic Photo Color PRC

Figure 1: The 2x2 Experimental Design of The Study

Study Materials

A sample of 140 2x2 slides drawn from a large pool of 700 slides developed by Berry (1977) and used in research by Berry (1977) and other researchers (Wieckowski, 1980; Lertchalolarn, 1981; Berry, 1982), was the original 35mm pictorial stimuli. The 140 were in both B&W and realistic color versions. These 140 slides were randomized and randomly divided by a computer program using the random-number-generator function between the old set (O) and the new set (N) (distractors). The order of this randomization and the assignment were used to construct the recognition test of the pictorial recognition memory task. The random division resulted in 66 slides to the old and 74 slides to the new set.

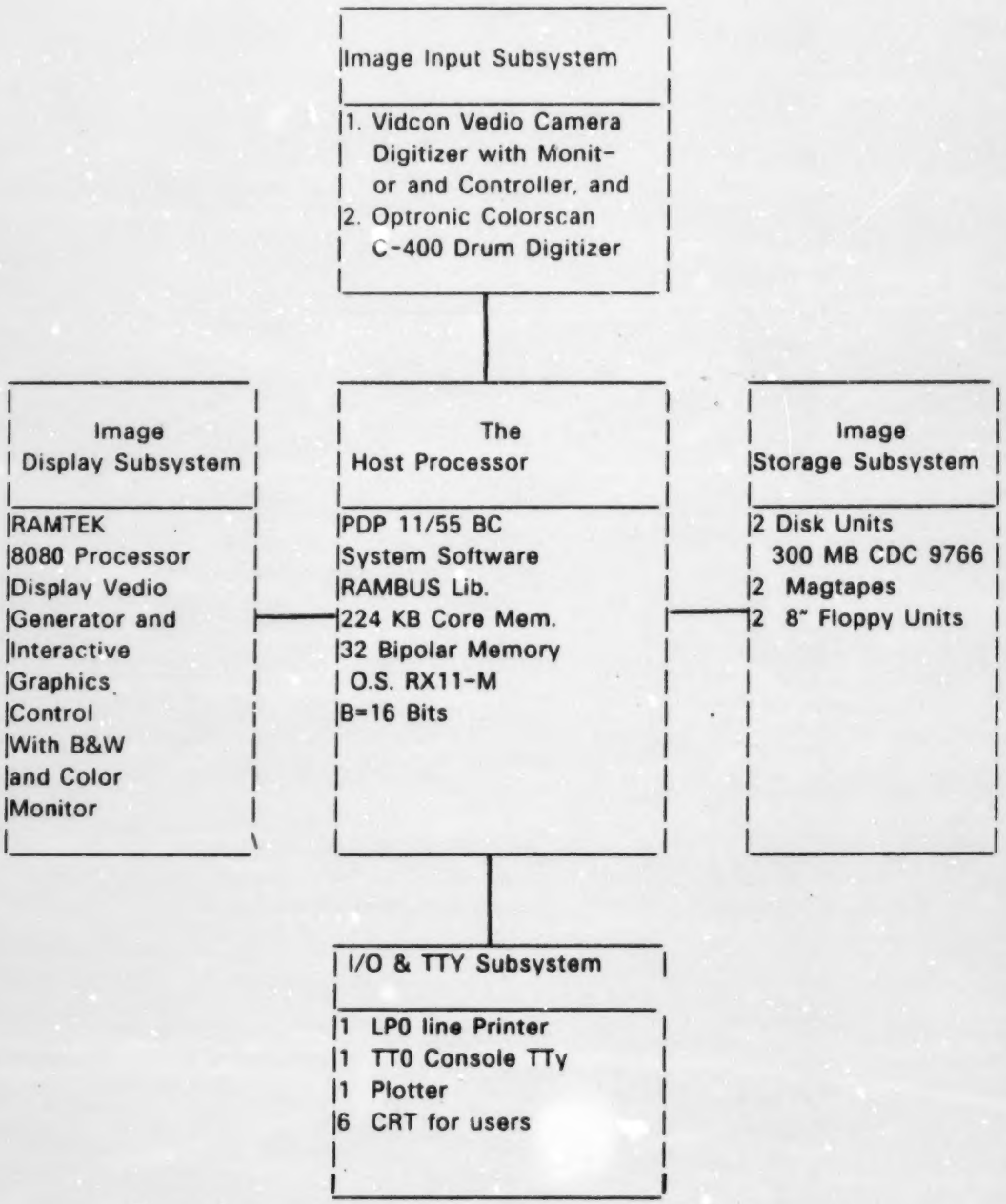
The square image format is the most common format in digital image processing (512x512 pixels). This format is the one that is also supported by the Pattern Recognition Laboratory System (PRL) in the Department of Electrical Engineering at the University of Pittsburgh. A simplefied functional diagram based on Sze (1982) is shown in Figure 2.

The image input subsystem, particularly the Optronic C-400, was interfaced to digitize the central square portion of the 35mm B&W negatives which was about 24x24mm. So, the original had to be trimmed to produce the photographic treatments to match the digital image contents. An Optical Slide Duplicator was used in producing the photographic B&W (PBW) and the photographic realistic color (PRC) from the original 35mm. The above copying system was copying only the central portion of each 35mm slide (24x24mm) by masking the rest of the slide scene.

The production of the digitized treatments was done by first digitizing the 140 35mm negatives of the original B&W version using the high precision Optronic C-400 image input subsystem. The 140 pictures were digitized, satisfactorily matching their counterparts in the photographic treatments.

Three different digital images were selected randomly and enhanced utilizing the PRL image processing routines by two different pixel-by-pixel image contrast corrections (Todhunter, 1978). The same digital images were pseudo-colored by four different pseudo-color tables. Twenty one slides were photographed from the RAMTEK display subsystem of the PRL where photographing the RAMTEK display is considered the best way o get a hard-copy of the digital image (Sze, 1982) . These 21 slides were as follows:

Figure 2: The PRL Facility: A Functional Block Diagram



1. Three original digitized B&W images (no enhancement done),

2. Three digitized B&W images enhanced by method one of the two methods,

3. Three digitized B&W images enhanced by the other method.

4. Three digitized pseudo-colored images by pseudo-color table-1,

5. Three digitized pseudo-color images by pseudo-color table-2,

6. Three digitized pseudo-color images by pseudo-color table-3, and

7. Three digitized pseudo-colored images by pseudo-color table-4.

Those 21 slides were randomized and displayed to a total of 30 judges from the same population (university students) using a seven point judgment scale. The seven points were: Extremely Poor, Very Poor, Poor, Fair, Good, Very Good, and Extremely Good to each picture of the 21 pictures.

The judgment data were analyzed by using One-Way Analysis of Variance with Repeated Measures (treatments) followed up by Tukey-B multiple comparison test. The judgments for the digitized B&W versions were significant ($F=3.28$; $df=2,58$; $P=0.044$). The digitized B&W (no enhancement) was found to be judged significantly higher than one of the two other methods and just higher than the other. So, the digitized B&W (DBW) treatment was produced by photographing the original digitized B&W images.

The judgments for the pseudo-color versions (four methods) were not significantly different ($F=2.60$; $df=3,87$; $P=0.06$). The pseudo-color method that was judged to be the highest was used in the production of the digitized pseudo-color (DPC) treatment.

The Procedures of The Experimentation

1. Instructions about the task sequence and the subject role and performance were read and explained by the investigator. All means were used to make those instructions fully understood by subjects individually or in groups.

2. Subjects were assigned randomly to the four experimental treatments prior to coming to the experimentation session. Subjects assigned to the color treatments were not to be color blind. If color blindness was detected, the subject would have to be excluded from the analysis None was excluded from the analysis because of color blindness.

3. The old set (66 slides) was projected at the rate of 500ms (half a second) using the computer based projection system described in the study instrumentation.

4. Subjets were given a five minute break before proceeding to take the pictorial recognition memory test (T).

5. The pictorial recognition memory test (T) was projected at the rate of 10 seconds to each slide using the computer based projection system described in the instrumentation section. Subjects were required to respond to each picture in the test using an answer form that was combining both the Yes-No method and the Confidence Rating method. The number of each slide in the pictorial recognition memory test (T) was projected in a window at the lower right corner of the picture to guide subjects to mark the answer to the correct number.

The Study Instrumentation and Environment

The administration of the pictorial recognition memory task was done individually and in small groups in a classroom-like situation. The projection was from the rear screen. It was an interactive computer based projection system. The system components were:

1. Two Kodak Ektagraphic III AF slide projectors (labeled PR#1 and PR#2), one super-wide angle projection lens for PR#2, extension cables, one projector stand and different high projection tables.

2. One Commodore SuperPET SP9000 Microcomputer with 96 Kb RAM and dual processors : the 6502 processor (same as the Commodore CBM 8032 microcomputer) and the 6809 processor with Waterloo Micro Software (MicroBASIC, MicroFortram, MicroPASCAL, MicroAPL, MicroCOBOL, 6809 Assembler, Linker-Loader, Monitor and MicroEDITOR). One CBM 8050 dual drive floppy disk of approximately 1 MB of storage.

3. One Projector Interface was developed and assembled by the investigator to be used in Pictorial Recognition Memory Research. The Projector Interface is connected to the IEEE-488 Parallel User Port of the SuperPET on the 6502 processor mode via an assembled cable. The Projector Interface was connected to the two slide projectors: PR#1 and PR#2. The Projector Interface was driven by the "CONTROL PROGRAM" written in Commodore BASIC 4.0. The execution of the CONTROL PROGRAM was controlled by the Real-Time Clock in the computer system.

The projector PR#2 was equipped with the super-wide projection lens and was used to project the pictures of the old set (O) and the pictorial recognition memory test (T) on the screen while the projector PR#1 was projecting the picture number on the window in the pictorial recognition memory test (T). The program "CONTROL PROGRAM" was driving the two projectors according to the pictorial recognition memory task specifications in the program. This program was also printing on the SuperPET CRT the slide number currently on the screen. The user had to load and change the carousels on the projectors as the task progressed.

The total projection time for the old set (O), 66 slides, was one minute, 29 seconds and 149 milliseconds. The projection time for the pictorial recognition memory test Part#1 (slides: 1-70) was 12 minutes, 48 seconds and 883 milliseconds .The projection time for the pictorial recognition memory test Part#2 (slides: 71-140) was 12 minutes, 48 seconds and 883 milliseconds which was the same as Part#1. The subjects were given a five minute break after the presentation of the old set (O) before the beginning of the pictorial recognition memory test (T) . The total time of the experiment was 32 minutes, 48 seconds and 915 milliseconds.

The Computational Procedures of The SDT Parameters of Recognition

The computational procedures of Yes-No signal detection parameters for the pictorial recognition memory , d', A_G, were done from the 2x2 signal detection matrix (sometimes called the 2x2 stimulus-recognition matrix). The construction was based on the analogy between the detection and recognition processes. The old set (O) is viewed as (Signals + Noise) and the new set (N) ,the distractors , is viewed as (Noise Only) as in the signal detection terminology. Figure 3 shows the 2x2 SDT/Stimulus-Recognition matrix that summarizes the SDT approach to the pictorial recognition memory processes.

		SUBJECT'S RESPONSE		
		YES (o)	NO (n)	Row total
S T I M U L U S	OLD (O) P(O)	F(o,O) P(o|O) Hit Rate P(o,O)	F(n,O) P(n|O) Miss Rate P(n,O)	Signals + Noise O
	NEW (N) P(N)	F(o,N) P(o|N) F.A.Rate P(o,N)	F(n,N) P(n|N) C.R.Rate P(n,N)	Noise N
				(O+N)

Figure 3: The 2x2 SDT/Stimulus-Recognition Matrix

The above mentioned SDT measures of pictorial recognition memory were computed by the following formulae:

$$d' = z[P(o|O)] - z[P(o|N)]$$

and

$$A' = .5 + \{[(P(o|O) - P(o|N))(1 + P(o|O) - P(o|N))]/[4P(o|O)(1 - P(o|N))]\}$$

and

$$A_G = \{P(o|O) + [1 - P(o|N)]\}/2$$

This estimator of the area under ROC was described by Green and Swets (1966) and its formula was found in Craig (1979).

$$P(o,O) = F(o,O)/(O+N)$$

and

$$P(o|O) = P(o,O)/P(O) = F(o,O)/O$$

where

F(*,*)	is the frequency in the designated cell of the matrix.
P(*,*)	is the joint probability of that cell.
O	is the number of the old set (O).
N	is the number of the new set (N).
(O+N)	is the total number of valid responses.
z[P(o|N)]	is the z-score of the probability of the occurrence of the response old (o) when the stimulus is (N), False Alarm,
z[P(o|O)]	is the z-score of the probability of

the occurrence of the response old (o)

when the stimulus is (O), Hit

P(O) is the a priori probability of old set in the test (T)

P(N) is the a priori probability of new set in the test (T)

A computer program "SIGNAL.FOR" was written by the investigator in Fortran language for the DEC 10/20 computers to calculate the above signal detection measures for pictorial recognition memory based on the Yes-No analysis. The program calculates the signal detection parameters from reading the subject's raw recognition data based upon the data descriptions in the file "SIGNAL.DDF". The program outputs a hardcopy of the signal detection analysis report for every subject and a disk file "SIGNAL.OUT" to be used in the further statistical analyses by the major statistical packages (SPSS, BMDP, etc.).

The Statistical Hypotheses

To investigate the research questions of the study, the SDT parameters were computed to each subject in the study. The three signal detection measures, d', A' and A_G, of the pictorial recognition memory were computed. The following null statistical hypotheses were tested. μ (Mue) is the population mean in the designated experimental condition.

1. The interaction effect of color modes and imagery modes is not statistically significant.

2. μ(Color) = μ(B&W), i.e., the main effect of color is not statistically significant.

3. μ(Photographic Imagery Mode) = μ(Digitized Imagery Mode), i.e., the main effect of imagery modes is not statistically significant.

4. $\mu_1=\mu_2=\mu_3=\mu_4$, i.e., there is no significant difference between the means among the four treatments.

5. μ(Photographic Color) = μ(Pseudocolor), i.e., the difference between the means of photographic color (realistic) and pseudocolor is not statistically significant.

6. μ(Digitized B&W) = μ(photographic B&W), i.e., the difference between the means of B/W photographic and digitized B&W is not statistically significant.

7. μ(digitized B&W) = μ(Pseudocolor Digitized), i.e., the difference between the means of digitized B&W and pseudocolor digitized is not statistically significant.

8. μ(photographic B&W) = μ(Color Photographic), i.e., the difference between the means of B/W photographic and color photographic is not statistically significant.

TWO-WAY ANOVA, TWO-WAY ANOVA (Repeated Measures) and ONE-WAY ANOVA followed-up by the Tukey-B will be used to test the above statistical hypotheses. The level of significance that will be used to reject or retain any null hypothesis will be at (0.05). The Statistical Package of The Social Sciences (SPSS) and/or the Biomedical Computer Programs P-Series (BMDP) will be used in the statistical analysis.

Findings and Results

The four experimental groups/treatments were denoted as: Digitized B&W (Group 1 .1), Digitized Pseudo-color (Group 1.2), Photographic B&W (Group 2.1) and Photographic Realistic color (Group 2.2). Table 1 shows the descriptive statistics of the recognition memory measures for the four experimental groups.

Table 1: Means and Standard Deviations of the SDT Measures By the Four Experimental Groups

The Measure		Group 1.1	Group 1.2	Group 2.1	Group 2.2
SDT Detectability, d'					
	Mean	0.3314	0.2479	0.4120	0.5071
	SD	0.1079	0.1634	0.1839	0.2697
Area Under ROC, A'					
	Mean	0.6153	0.5868	0.6371	0.6596
	SD	0.0330	0.0528	0.0520	0.0731
Area Under ROC, A_G					
	Mean	0.5644	0.5481	0.5788	0.5968
	SD	0.0207	0.0315	0.0351	0.0513

Testing The Statistical Hypotheses

The testing of the statistical hypotheses was carried over the three pictorial recognition memory measures. The statistical analysis was consisted of two statistical procedures: two-way analysis of variance and one-way analysis of variance. The first three hypotheses were tested at once by the two-way analysis of variance and the last five hypotheses were tested at once by the one-way analysis of variance followed-up by the multiple comparisons test of Tukey-B. The four experimental groups were of the same size (24). The F-Test is robust against the violation of the homogeneity of variance when the experimental groups are equal in size (Huck, 1974, Maisel, 1972).

Testing Hypothesis 1, 2 and 3

Table 2 shows the summary of the Two-Way ANOVA for d', A' and A_G as measures of pictorial recognition memory.

The results of testing hypotheses were as the following:

1. Hypothesis No.1 was rejected (d' F=5.283, df=1,92, P=0.024; A' F=5.244, df=1,92, P=0.024; A_G F= 5.329, df=1,92, P=0.023). This means that the interaction of color mode and the imagery mode is significant at α=.05.

2. Hypothesis No.2 was retained (d' F=0.022, df=1,92, P=0.882; A' F=0.071, df=1,92, P=0.791; A_G F=0.013, df=1,92, P=0.91). This means that the main effect of color is not significant at α=.05.

3. Hypothesis No.3 was rejected (d' F=19.125, df=1,92, P=0.000; A' F=17.995, df=1,92, P=0.000; A_G F=18.003, df=1,92, P=0.000). This means that the main effect of imagery mode is significant at α=.05.

Table 2: TWO-WAY Analysis of Variance Summary For The SDT Detectability Measure d', the area under ROC, A' and A_G

Source	SS	DF	MS	F	Prob.
The Measure d':					
Main Effects:					
IMMODE(I)	0.693	1	0.693	19.125	0.000
COLOR(C)	0.001	1	0.001	0.022	0.882
Interaction(IxC)	0.191	1	0.191	5.283	0.024
Residual	3.332	92	0.036		
Total	4.217	95	0.044		
The Measure A':					
Main Effects:					
IMMODE(I)	0.054	1	0.054	17.995	0.000
COLOR(C)	0.000	1	0.000	0.071	0.791
Interaction(IxC)	0.016	1	0.016	5.244	0.024
Residual	0.274	92	0.003		
Total	0.344	95	0.004		
The Measure A_G:					
Main Effects:					
IMMODE(I)	0.024	1	0.024	18.003	0.000
COLOR(C)	0.000	1	0.000	0.013	0.910
Interaction(IxC)	0.007	1	0.007	5.329	0.023
Residual	0.122	92	0.001		
Total	0.152	95	0.002		

Testing Hypothesis 4, 5, 6, 7 and 8

Tables 3 and 4 show the One-Way ANOVA summary and the Tukey-B multiple comparison test for d', A' and A_G. The results of the tests of the statistical hypothesis 4, 5, 6, 7 and 8 are as the following:

1. Hypothesis No.4 was rejected (d' F=8.143, df=3,92, P=0.0001; A' F=7.770, df=3,92, P=0.0001; A_G F=7.781, df=3,92, P=0.0001). This means that the differences among the means of the four treatment groups are statistically significant at α=.05.

2. Hypothesis No.5 was rejected. The two treatment groups do not fall in one homogeneous subset at α=.05, see Table 4. This means that there is a significant difference between the photo realistic color and the digital pseudo-color.

3. Hypothesis No.6 was retained. The two treatment groups fall in one homogeneous subset at α=.05, see Table 4. This means that there is no significant difference between digitized B&W and the photographic B&W treatments.

4. Hypothesis No.7 was retained. The two treatment groups fall in one homogeneous subset at α=.05, see Table 4. This means that there is no significant difference between the digitized B&W and the digitized pseudo-color treatments.

5. Hypothesis No.8 was retained. The two treatments fall in one homogeneous subset at α=.05, see Table 4. This means that there is no significant difference between the photographic B&W and the photo realistic color treatments.

Table 3: ONE-WAY Analysis of Variance Summary For The SDT detectability Measure d', the area under the ROC A' and A_G

Source	SS	DF	MS	F	Prob.
The Measure d':					
Between Groups	0.8848	3	0.2949	8.143	0.0001
Within Groups	3.3323	92	0.0362		
Total	4.2171	95			
The Measure A':					
Between Groups	0.0695	3	0.0232	7.770	0.0001
Within Groups	0.2744	92	0.0030		
Total	0.3439	95			
The Measure A_G:					
Between Groups	0.0308	3	0.0103	7.781	0.0001
Within Groups	0.1216	92	0.0013		
Total	0.1524	95			

Table 4: Multiple Comparison Test of Tukey-B at $\alpha = .05$ For The SDT detectability Measure: d', the area under ROC A' and A_G

The Measure d':				
Experimental Group	Group 1.2	Group 1.1	Group 2.1	Group 2.2
Sorted Means	0.2479	0.3314	0.4120	0.5071
Homogeneous Subset 1	———	———		
Homogeneous Subset 2		———	———	
Homogeneous Subset 3			———	———

The Measure A':				
Experimental Group	Group 1.2	Group 1.1	Group 2.1	Group 2.2
Sorted Means	0.5868	0.6153	0.6371	0.6596
Homogeneous Subset 1	———	———		
Homogeneous Subset 2		———	———	
Homogeneous Subset 3			———	———

The Measure A_G:				
Experimental Group	Group 1.2	Group 1.1	Group 2.1	Group 2.2
Sorted Means	0.5481	0.5644	0.5788	0.5968
Homogeneous Subset 1	———	———		
Homogeneous Subset 2		———	———	
Homogeneous Subset 3			———	———

and the use of the parameters d' A' and A_G to measure the recognition process should be considered for accuracy analysis of recognition data. These three measures were consistent in all the decisions involved in testing the eight hypotheses of this study. The new parameters A' and A_G are accurate alternative distribution-free measures of recognition memory. It is suggested,in view of the findings of this study, that the parameters A' and A_G should be used when the experimenter is in doubt of the parametric assumptions of the parametric measure of detectability (d').

Based on the findings and the above discussions, some conclusions and recommendations could be drawn:

1. The signal detection theory (SDT) parameters of Yes-No experiments, d', and A_G are consistent and should be used for accuracy analysis of the recognition data.

2. The two distribution-free SDT parameters of the area under the ROC curve, A' and A_G offer the same accuracy of the d' (SDT index of detectability) in analysing recognition data. A' and A_G should be used if the experimenter is in doubt of the distributional assumptions of the parametric measure d'.

3. Pseudocolor methods should be used in digital images with adjustment to each image to meet the purpose of making the picture suitable to the learning task. In recognition and detection, various pseudocolor methods should be used, not just one color table.

4. The digitized B&W images could be used in learning at the same effect of the photographic B&W pictures. This conclusion could be applied to support any computerized visual learning system to use pictorial data bases and also support the computerized slide-making for learning and presentation of information.

5. The main effect of color is not significant, but the main effect of the imagery mode is significant. Given the result that their interaction is significant, the effect of these two factors is not additive. On the contrary, these two factors systematically interact and affect the

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recognition. This suggests that the interaction of the two factors should be considered in the interpretation and design of pictorial learning in such tasks.

6. The contention of realism theories is partially supported while the cue-summation theory is not supported. However, both of these theories are not suitable to interpret the zero effect of color in both the two imagery modes.

7. The failure of the applicability of both the two contentions of of realism theories and the cue-summation theory should be attributed to the learner variables more than to the pictorial design and attributes.

8. The above conclusion supports the view that learner variables should be also considered in the interpretation and design of learning tasks. Learner variables such as learning and thinking styles, cognitive styles, and other personality traits should be considered in the design and interpretations of recognition and learning. This suggests follow-up studies or new studies that take into consideration the learner variables in the learning process.

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References

Andrews, Harry C. Digital Image Restoration: A Survey. Computer, 1974, 7(5), 36-45.

Banks, William P. Signal Detection Theory and Human Memory. Psychological Bulletin, 1970, 74(2), 81-99.

Berch, Daniel B. Measures of sensitivity and response Bias for Probe-Type Serial Memory Task. Journal of Exprimental Child Psychology, 1975, 20, 149-158.

Berry, L. H. An Exploratory Study of the Relative Effectiveness of Realistic and Non-realistic Color in Visual Instructional Materials. PhD thesis, The Pennsylvania State University, 1974.

Berry, Louis H. The Effects of Color Realism on Pictorial Recognition Memory. Paper Presented at the Annual Convention of the Association for Educational Communications and Technology, Miami Beach, Fl., 1977.

Berry, Louis H. Signal Detection Analysis of Color Realism Data. Instructional Communications and Technology Research Reports, 1982, 13(1), 1-5.

Bourbon, W. Tom. Psychophysics and Perception. In Exprimental Psychology: Research Tactics and Their Applications. Scott, Foresman and Company, Glenview, Illinois, chap. 7, pages 248-305. 1978.

Chute, A. G. Effects of Color and Monochrome Versions of a Film on Incidental and Task-Relevant Learning. Educational Communications and Technology Journal, 1980, 28(1), 10-18.

Craig, Angus. Nonparametric Measures of Sensory Efficiency For Sustained Monitory Tasks. Human Factors, February 1979, 21(1), 69-78.

Descy, Don E. Color in Media: Is it Really Worth The Extra Cost? International Journal of Instructional Media, 1981, 8, 261-266.

Dwyer, Francis M. Adapting Visual Illustrations For Effective Learning. Harvard Educational Review, 1967, 37, 250-263.

Dwyer, F. M. Color as an Instructional Variable. AV Communication Review, 1971, 19(4), 399-416.

Gonzalez, Rafael C. and Wintz, Paul. Digital Image Processing. Reading, Massachusett:

Green, David M. and Swets, John A. Signal Detection Theory and Psychophysics. New York: John Wiley and Sons, Inc. 1966.

Grier, J. Brown. Non-Parametric Indexes For Sensitivity and Bias: Computing Formulas. Psychological Bulletin, 1971, 75(6), 424-429.

Hall, Ernest L. Computer Image Processing and Recognition. New York: Academic Press 1979.

Hodos. William. Non-Parametric index of Response Bias For Use in Detection and Recognition Experiments. Psychological Bulletin, 1970, 74(5), 351-354.

Huck, Schuyler W. et al. Reading Statistics and Research. New York: Harper & Row, Publishers 1974.

Lertchalolarn, Chawlert. The Interactive Effects of Color Realism, Pictorial Attributes, and Cognitive Style on Pictorial Information Processing. PhD thesis, University of Pittsburgh, 1981.

Lipkin, Bernice Sacks and Rosenfeld, Azriel (Eds.). Picture Processing and Psychopictorics. New York: Academic Press 1970.

Lockhart, Robert S. and Murdock, Bennet B. Memory and the Signal Detection Theory. Psychological Bulletin, 1970, 74(2), 100-109.

Long, Gerald M. and Wagg, Wayne L. Limitations on the Practical Applications of d' and B Measures. Human Factors, 1981, 23(3), 285-290.

Maisel, Herbert and Gnugnoli, Giuliano. Simulation of Discrete Stochastic Systems. Chicago: Science Research Associates, Inc. 1972.

Moik, Johannes G. Digital Processing of Remotely Sensed Images. Washington, D.C.: NASA Scientific and Technical Information Branch 1980.

Murdock, Bennet B. Signal Detection Theory and Short-Term Memory. Journal of Exprimental Psychology, 1964, 70(5), 443-447.

Murdock, Bennet B. ,Jr. Human Memory: Theory and Data. Potomac, Maryland: Lawerence Erlbaum and Associates, Inc. 1974.

Murdock, Bennet B., Jr. Recognition Memory. In C. Richard Puff (Ed.), Handbook of Research Methods in Human Memory and Cognition. Academic Press, New York, chap. 1, pages 1-26. 1982.

Myatt, Barbara. The Interaction of Cognitive Style and Pictorial Attributes in a Recognition Memory Task. PhD thesis, University of Georgia, 1974.

Norman, Donald A. A Comparrison of Data Obtained With Different False-Alarm Rates. Psychological Bulletin, 1964, 71(3), 243-246.

Pollack, Irwin and Norman, Donald A. A Non-Parametric Analysis of Recognition Expriments. Psychonometric Science, 1964, 1, 125-126.

Analysis of Recognition Memory. Psychonometric Science, 1964, 1, 327-328.

Richardson, John T. E. Non-Parametric Indexes of Sensitivity and Response Bias. Psychological Bulletin, 1972, 78(6), 429-432.

Severin, Werner. Another Look at Cue Summation. AV Communication Review, 1967, 15, 233-245.

Swets, John A. and et.al. Decision Processes in Perception. In John A. Swets (Ed.). Signal Detection and Recognition by Human Observers. John Wiley & Sons, Inc., New York, chap. 1, pages 3-57. 1964.

Swets, John A. and Pickett, Ronald M. Evaluation of Diagnostic Systems: Methods From Signal Detection Theory. New York: Academic Press 1982.

Sze, T. W. Pattern Recognition Laboratory: User's Handbook, First Draft. Department of Electrical Engineering, University of Pittsburgh: University of Pittsburgh, 1982.

Todhunter, John and Lee, Mike M. Some Basic Image Processing Programs Manual. Department of Electrical Engineering, University of Pittsburgh: University of Pittsburgh, 1978.

Wieckowski, Theodora J. The Interactive Effects of Color and Cognitive Style on a Pictorial Recognition Memory Task. PhD thesis, University of Pittsburgh, 1979.

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Discussion and Conclusions

Findings of the study suggest that the use of the digitized B&W images in computerized instruction and information transmission of pictorial information provides the same pictorial information as of the photographic B&W pictures. This is based on the lack of significance of the difference between the photographic B&W and the digitized B&W. This could be interpreted as that the change of the mode of pictures from photographic to digitized form does not change the features that the human viewers need to recognize these pictures. This conclusion is important in the design of visual learning in future developments in computer based visual learning systems by constructing pictorial banks or pictorial data bases of naturalistic scenes that could be retrieved for learning and instruction.

It was expected, in view of the cue-summation theory of learning, that adding pseudo-color to the digitized B&W images would increase the distinctiveness and recognition of these pictures in the task. The lack of the significance between the digitized B&W and the digitized pseudo-color could be because of the use of one pseudocolor method. So, this result should be limited to the case of using one pseudocolor method. Using one pseudo-color method could have made the pictures have much the same of their color look. This may suggest that the use of more than one pseudocolor method (color tables) and adjusting these color methods could make the picture more distinctive and recognizable than its digitized B&W counterpart. It should be noticed that the pseudocolor (single method) is different than the non-realistic color in other studies (Berry, 1977, 1982; Lertchalolarn,1981). The non-realistic color (NRC) used in those studies was based on the original picture realistic

color complements which are more distinctive from one picture to another. In view of this study's findings and the other research on color realism, the digitized pseudocolor could be more effective in learning and instruction if it is used purposefully in multiple methods and adjusting them to each picture to make them more suitable to the objectives of the learning task.

The result that there is no significance in the difference between the photographic B&W and the photographic realistic color supports similar findings (Myatt, 1974). However, this doesn't support other studies (Berry, 1977; Wieckowski, 1979; Lertchalolarn, 1981). This could be interpreted by the view that the realistic scenes need more processing time than the black and white which is not given in recognition experiments since the acquisition time of the old pictures is always around 500ms.

With regard to the finding that the photographic realistic color is significantly different than the digitized pseudocolor, this finding could be interpreted by the contention of the realism theories. So, this concludes that the realistic color is preferred more than digitized pseudocolor in learning from realistic scenes.

The findings of this study partially support the contention of realism theories. The cue-summation theory was not supported by any of the findings. However, both realism theories and the cue-summation theory can not predict or interpret the lack of the significance of the difference between the digitized B&W and the digitized pseudocolor and also the photographic B&W and the photographic realistic color.

The approach of modeling the pictorial recognition by the signal detection theory

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